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# DRAFT CSA STANDARD FOR REPAIR WELDING OF FIXED STEEL OFFSHORE STRUCTURES

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WELDING SECTION

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REPORT ERP/PMRL 84-72(TR)

# Draft CSA Standard for Repair Welding of Fixed Steel Offshore Structures

by

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## ABSTRACT

The clauses contained in the report relate to repairs of steel fixed offshore structures made during fabrication before a structure enters service. The report presents the proposed clauses and a commentary on each clause. Many clauses can be found in existing codes; however, it was necessary to make several alterations and additions to reflect the higher fabrication standard, required for these structures. The proposed clauses reflect the importance of structural integrity while not making the requirements overly restrictive. These clauses have been submitted to the Welding Working Group of the Canadian Standards Association (CSA) Task Force on Steel Fixed Offshore Structures.

## INTRODUCTION

Fixed steel offshore structures are designed for an operating life of between 20 to 30 years. Design loads and minimum anticipated temperatures used are often for a 100 year return period. Once in place it becomes extremely difficult and costly to repair many sub-surface structural parts.

During fabrication, defects, flaws and sub-standard workmanship will inevitably occur, often for seemingly inexplicable reasons, although hindsite will often provide the reasons. In the majority of cases it is cost effective to correct these problems by repair welding. However, for these types of structures the repairs made must meet and exceed the original design properties. Thus, these repairs must be made to a higher standard than the same type of repair for other types of structures.

In reviewing the various existing standards, which address structural repairs during fabrication, it was felt that no one standard was sufficient. The proposed clauses for the CSA standard are a compilation of various clauses from several existing standards. Several of these clauses were altered to improve the quality control on the repairs and a section has been added to allow the acceptance of some defects based on a fracture mechanics evaluation. These clauses were presented as a first draft for discussion at the CSA. Alterations were made and a second draft was submitted to be included as a supplement to the existing W59 standard.

The first section lists the clauses as originally proposed while the second section is a commentary on each clause. The third section discusses the alterations and presents the second draft.

## REPAIRS

### 1 General

1.1 This section covers repairs made during fabrication before a structure enters service. Part 1 refers to repairs in general and is in addition to the Clauses of Parts 2 and 3.

1.2 If a piece or member fails to meet the required workmanship standards the defects may be rectified by grinding, machining or welding depending on the defect type.

Alternative Section 1.2

1.2 If a piece or member fails to meet the required workmanship standards the defects may be rectified by grinding, machining or welding, depending on the defect type, or, at the option of the engineer, they may be accepted, provided that the defects are judged to be acceptable on the basis of an engineering critical assessment involving consideration of anticipated service conditions, loading, accurately established defect dimensions and material properties including fracture toughness properties.

1.3 Welds of insufficient strength, ductility or notch toughness are to be completely removed prior to repair.

1.4 The mechanical properties of repair welds are to satisfy the minimum specified properties of the steel in question.

1.5 All repair welds are to be made in accordance with the requirements of this standard and to a qualified repair welding procedure. A repair welding specification is to be prepared which shall include the following: steel grade and thickness, joint/groove design, welding process, welding consumables, welding parameters, principal welding position, preheat/interpass temperature, post-weld-heat treatment, method for removal of defects, preparation of weld area, and minimum/maximum repair length/depth.

1.6 The removal of weld metal or portions of the base material shall be done by grinding, machining, oxygen cutting or air-carbon-arc gouging. The use of oxygen cutting or air-carbon-arc gouging is to be followed by grinding, removing the affected material.

1.7 Whenever a defect is removed, the gouged and ground area is to be examined by magnetic particle testing or other suitable methods to verify complete removal.

1.8 Repair welding is to use approved, qualified, extra-low hydrogen welding consumables applying an appropriate preheating and working/interpass temperature. Generally the preheating and working temperature when making shallow and local repairs is to be raised 25°C above the level used for production welding and at least 100°C (see Table 1). The working temperature is to be maintained until the repair has been completed.

Table 1. Minimum preheating and working/interpass temperature °C (1).

| Carbon equivalent (CE) (2) | Maximum thickness at weld area | | |
|---|---|---|---|
| | $t \leq 20$ mm | $20 < t \leq 30$ mm | $t > 30$ mm |
| $\leq 0.41$ | 5 | 5 | 75 |
| 0.41 - 0.43 | 5 | 50 | 100 |
| 0.43 - 0.45 | 50 | 100 | 125 |
| 0.45 - 0.47 | 100 | 125 | 150 |
| 0.47 - 0.50 | 125 | 150 | 175 |

(1) Other temperatures may be accepted when the actual chemical composition and the welding procedure is given.

(2) $CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$

(ladle analysis)

IIW Equation

1.9 To ensure sound repair welds, the single repair length is not to be shorter than approx. 100 mm.

1.10 The use of post-weld-heat treatment (PWHT) may be necessary for repair welds to attain the required mechanical properties. PWHT shall be performed after repair welding for joints where PWHT was originally specified.

## 2 Repair of Base Material

2.1 Minor surface discontinuities may be removed by grinding or machining, blending the gouged areas smoothly into the surrounding material. The repaired area shall have a thickness in excess of the minimum required for the designed loads and the ground/machined area shall not give rise to a stress concentration which would result in fatigue damage under service conditions.

2.2 When base material is to be repaired by welding the maximum repair depth of rolled steel and steel forgings is normally to be limited to 20% of the nominal thickness. For steel castings the maximum repair depth is to be restricted to 75% of the nominal thickness. Casting defects are to be repaired after homogenization treatment.

2.3 When repair welding is carried out on steel supplied in a heat-treated condition, reheat treatment may be required. Steel castings and forgings are to be post-weld-heat treated after repair welding.

2.4 Removal of temporary fittings such as strongbacks, dogs and lugs, shall be made in a manner which will not result in gouges in the base metal. Remaining weld metal from such attachments shall be ground smooth with the base material surface removing any undercut. These welds are to be inspected for cracks as per Clause 1.7 at least 48 h after joint completion. Cracks are to be removed by grinding and repaired to the requirements of this standard.

## 3 Repair of Welded Joints

3.1 There is no restriction on the size of defects in a weld which may be repaired by welding. Long defects may be required to be repaired in several steps to avoid overloading or cracking. Each repair step is to be controlled so as not to cause plastic deformation of the remaining material when removing the defect.

3.2 Unless otherwise specified, welds containing defects shall be corrected at the option of the Contractor, either by removing and replacing the entire weld or as follows:

a) overlap or excessive convexity: reduce by removal of excess weld metal;

b) excessive concavity of weld or crater, undersize welds, undercutting: clean and deposit additional weld metal;

c) excessive weld porosity; excessive slag inclusions, incomplete fusion: remove defective portions and reweld;

d) cracks in welds or base metal: ascertain the extent of the crack by the use of dye penetrant, magnetic particle inspection or equally positive means, remove the crack and reweld.

3.3 Defective portions of a weld shall be removed without substantial removal of the base material.

3.4 Additional weld metal to compensate for deficiency in size shall be deposited using an approved electrode preferably smaller than that used for making the original weld, and preferably not more than 4 mm in diameter. The surfaces shall be cleaned thoroughly before welding.

3.5 Where work performed subsequent to the making of a deficient weld has rendered the weld inaccessible or has caused new conditions that would make the correction of the deficiency dangerous or ineffectual, the original conditions shall be restored by removing welds or members or both before making the corrections, or else the deficiency shall be compensated for by additional work done according to an approved, revised design.

3.6 Non-structural Members: Improperly fitted parts which are non-structural may be cut apart and rewelded. Non-structural members distorted by welding shall be straightened by mechanical means, by carefully supervised application of a limited amount of localized heat, or by a combination of both methods. The temperature of heated areas as measured by approved methods shall not exceed 590°C for quenched and tempered steels or 645°C for other steels. Parts to be heated for straightening shall be substantially free from stress and from external forces, except those stresses from mechanical means used in conjunction with the application of heat.

3.7 Structural Members: Improperly fitted parts and members distorted by welding which are load carrying structural members may be repaired only to an approved procedure/design provided by the Engineer. The repaired part or member shall meet the same structural requirements as the original design.

## COMMENTARY ON PROPOSED CLAUSES FOR REPAIRS

The following documents have been consulted/used in preparing the draft section on Repairs:

DnV Rules for the Design, Construction and Inspection of Offshore Structures 1977 (with corrections 1981)
Z184 CSA Standard Z184-M1983 Gas Pipeline Systems
W59 CSA Standard W59-1982 Welded Steel Construction (Metal Arc Welding)
D1.1 AWS D1.1 1983 Structural Welding Code - Steel

Where a Clause or portion of a Clause has been taken from one of these documents reference is made to the originating document and Clause number. Additional commentary is added where necessary.

1 General

1.2 DnV 6.4.9.1

1.2(Alternative) The additional wording is based on Section 9.10.4.1 of CSA Z184. This would allow acceptance of some defects based on an engineering critical assessment. Obviously, the use of critical assessment would become part of the overall fracture control plan. This is a necessary point of discussion which should be addressed.

1.3 DnV 6.4.9.1.

1.4 DnV 6.4.9.1 Here the word "steel" refers to both base material and weld metal depending on the location of the repair.

1.5 The first sentence refers to any other requirements of the standard and specifically requires that the repair procedure be qualified by the appropriate tests. For joints which require only one qualification test for the whole structure, one qualification test demonstrating a repair procedure would be required. For joints which need to be qualified individually the repair procedure must also be qualified individually. For base material covered by Clause 2.2 qualification may need to be on an individual case basis while those cases covered under Clause 2.4 may require qualification once only. The remaining part of this Clause is a requirement of DnV 6.4.9.2.

1.6 This is a modified version of W59 Clause 5.10.2. Chipping has been excluded as it may result in re-entrant angles providing sites for slag entrapment and lack of fusion defects. Oxygen gouging has been removed as the excessive heat input of this process may exceed the heat input restrictions of a number of offshore grades of steels. Grinding after gouging is a requirement of DnV 6.4.9.3.

1.7 DnV 6.4.9.4.

1.8 DnV 6.4.9.5 Low hydrogen electrodes are to be used to reduce the risk of hydrogen cracking. Certifying authorities require that only approved electrodes be used. The electrodes used must be the same as those used in the qualification test. Preheat guidelines are those of DnV.

1.9 DnV 6.4.9.5 (last sentence).

1.10 Repair welding will result in the formation of residual stresses. PWHT has been shown to improve the toughness of a number of offshore grades of steels (see, for instance, Pisarski, H.G. and Harrison, J.D., Proc. 2nd Int. Conf. on Offshore Welded Structures, The Welding Institute, Abington, Cambridge, U.K., 1982. or Auerkari, P., Gren, P., and Wallin, K., Technical Research Centre of Finland, Research Report 217, Sept. 1983.) and welded joints apart from relieving residual stresses. Where residual stress removal is of prime concern PWHT should follow repair welding. Where residual stresses are not as important, PWHT may only be of value if there is a need to improve toughness. PWHT may result in lower toughness for some steels which rely on precipitate formation for toughness. Caution must be exercised in such cases.

## 2 Repair of Base Material

2.1 This clause is modeled after Clause 5.2.12.3 "Arc Burn Removal" of Z184. In instances where the base material contains small surface defects or discontinuities which may result in damage by fatigue or corrosion during service this Clause would allow repair to be effected by grinding the defect smooth. The Engineer would, however, have to check that such a repair does not diminish the strength (static or fatigue) of the member.

2.2 DnV 6.4.9.6.

2.3 DnV 6.4.9.6. The commentary of clause 1.10 also applies.

2.4 None of the codes consulted refer to the restoration of base material after the removal of temporary fittings in their respective sections on repair. These welds may initiate hydrogen cracks in areas which should be "base material" only according to the original design. This clause would ensure that such cracking is repaired before entering service. The Welding Working Group may decide to put this Clause, or one similar, in the general fabrication section. This is a point for the Group to discuss.

## 3 Repair of Welded Joints

3.1 DnV 6.4.9.7. First paragraph.

3.2 W59 5.10.1

3.3 W59 5.10.2. Last sentence. This is required to ensure that the original joint preparation dimensions are not exceeded.

3.4 W59 5.10.3

3.5 W59 5.10.4

3.6 and 3.7 Structural Members refers to members which are part of the primary load carrying structure (ie: tubular braces, columns, nodes, etc.). Non-structural Members refers to nonprimary load or non-load carrying members (ie: deck plate, parts of housing modules, etc.). The section for "nonstructural" members, Clause 3.6, comes from W59 5.10.5. For "structural" members any repairs for improper fit and distortion would require analysis by the Engineer such that any repairs do not affect structural integrity. The wording of these Clauses is subject to discussion depending on the exact definitions and names given to "Structural" and "Non-structural" members as referred to here.

## THE SECOND DRAFT

The above draft clauses were reviewed at a meeting of the Welding Working Group. Prior to this meeting it was decided that any welding codes for offshore structure fabrication should refer to existing national standards such as W47, W48 and W59. These standards should then contain suppliments referring specifically to offshore structures which the working group would prepare. The repair clauses would become part of the supplement to the W59 standard. The alterations to the clauses are as follows:

Clause 1.2 - It was agreed to use the alternate version which allows acceptance of certain defects based on an engineering critical assessment. However, a non-conformance report must be prepared to justify the exception.

Clauses 1.3 and 1.4 - Delete. These are, essentially, covered in W59. The non-conformance of welds in meeting specified mechanical properties is another reason for effecting repairs.

Clause 1.5 - The word "repair" in "repair welding procedure" was deleted so that a separate repair welding procedure was not necessary. This is acceptable for fillet and groove weld joints. For base material repairs a specific qualified welding procedure may be necessary and would have to be prepared.

Clause 1.6 - The words "removing the affected material" were deleted.

Clause 1.8 - Delete. This is covered in Clause 1.5 since the procedure, including electrodes and preheat temperatures, is qualified. Hence, Table 1 is also deleted.

Clause 1.9 - Delete. If the procedure is qualified then the length of repair is also qualified.

Clause 1.10 - The first sentence was deleted. An exception was added to the second sentence if it could be demonstrated that PWHT is not necessary.

Clause 2.1 - "Minor surface discontinuities" was changed to "Surface defects in the base material".

Clauses 2.2 and 2.3 - The working group wanted to delete both of these clauses as they felt that the Materials Working Group should revise the casting specifications. The author, however, feels that if repairs by welding are necessary then provisions should exist in the standard to deal with the situation. This requires further discussion and until resolved the author has retained clauses 2.2 and 2.3 in the second draft.

Clause 2.4 - Delete. Already covered in W59, although not directly obvious.

Clause 3.1 - Retain first sentence only. The remainder is more a commentary on suggested procedures and was felt to be not necessary.

Clause 3.2 - Delete. Already covered in W59.

Clauses 3.6 and 3.7 - Terms such as "primary", "secondary", "special", "structural" and "non-structural" need to be sorted out by the Task Force as a whole. For the purposes of the second draft the author has used the terms "Secondary" and "Special and Primary" to match current wording being used by the Materials Working Group.

The second draft, to which only minor modifications are expected, now follows:

REPAIRS

1 General

1.1 This section covers repairs made during fabrication before a structure enters service. Part 1 refers to repairs in general and is in addition to the Clauses of Parts 2 and 3.

1.2 If a piece or member fails to meet the required workmanship standards the defects may be rectified by grinding, machining or welding, depending on the defect type, or, at the option of the engineer, they may be accepted, provided that the defects are judged to be acceptable on the basis of an engineering critical assessment involving consideration of anticipated service conditions, loading, accurately established defect dimensions and material properties including fracture toughness properties. In such cases a non-conformance report is required.

1.3 All repair welds are to be made in accordance with the requirements of this standard and to a qualified welding procedure. A repair welding specification is to be prepared which shall include the following: steel grade and thickness, joint/groove design, welding process, welding consumables, welding parameters, principal welding position, preheat/interpass temperature, post weld heat treatment, method for removal of defects, preparation of weld area, and minimum/maximum repair length/depth.

1.4 The removal of weld metal or portions of the base material shall be done by grinding, machining, oxygen cutting or air-carbon-arc gouging. The use of oxygen cutting or air-carbon-arc gouging is to be followed by grinding.

1.5 Whenever a defect is removed, the gouged and ground area is to be examined by magnetic particle testing or other suitable methods to verify complete removal.

1.6 PWHT shall be performed after repair welding for joints where PWHT was originally specified except where it can be demonstrated that PWHT is not necessary.

2 Repair of Base Material

2.1 Surface defects in the base material may be removed by grinding or machining, blending the gouged areas smoothly into the surrounding material. The repaired area shall have a thickness in excess of the minimum required for the designed loads and the ground/machined area shall not give rise to a stress concentration which would result in fatigue damage under service conditions.

2.2 When base material is to be repaired by welding the maximum repair depth of rolled steel and steel forgings is normally to be limited to 20% of the nominal thickness. For steel castings the maximum repair depth is to be restricted to 75% of the nominal thickness. Casting defects are to be repaired after homogenization treatment.

2.3 When repair welding is carried out on steel supplied in a heat-treated condition, reheat treatment may be required. Steel castings and forgings are to be post-weld-heat treated after repair welding.

3 Repair of Welded Joints

3.1 There is no restriction on the size of defects in a weld which may be repaired by welding.

3.2 Defective portions of a weld shall be removed without substantial removal of the base material.

3.3 Additional weld metal to compensate for deficiency in size shall be deposited using an approved electrode preferably smaller than that used for making the original weld, and preferably not more than 4 mm in diameter. The surfaces shall be cleaned thoroughly before welding.

3.4 Where work performed subsequent to the making of a deficient weld has rendered the weld inaccessible or has caused new conditions that would make the correction of the deficiency dangerous or ineffectual, the original conditions shall be restored by removing welds or members or both before making the corrections, or else the deficiency shall be compensated for by additional work done according to an approved, revised design.

3.6 Secondary Members: Improperly fitted parts may be cut apart and rewelded. Secondary members distorted by welding shall be straightened by mechanical means, by carefully supervised application of a limited amount of localized heat, or by a combination of both methods. The temperature of heated areas as measured by approved methods shall not exceed 590°C for quenched and tempered steels nor 645°C for other steels. Parts to be heated for straightening shall be substantially free from stress and from external forces, except those stresses from mechanical means used in conjunction with the application of heat.

3.7 Special and Primary Members: Improperly fitted parts and members distorted by welding may be repaired only to an approved procedure/design provided by the Engineer. The repaired part or member shall meet the same structural requirements as the original design.